RITE GEOSYSTEMS

ENCARDIO RITE
METASENSING FOR MEGA STRUCTURES

APPLICATION NOTE

ONLINE STRUCTURAL HEALTH MONITORING OF BRIDGES

1 INTRODUCTION

Bridges form an important component of the transportation network of a nation. Their role is multifaceted, from boosting the economy by quick transportation of people and goods to strengthening the defense capabilities. Thus any damage or collapse of bridges due to their deteriorating performance can have wide-ranging consequences. The bridges must function safely at all times.

The design of the bridges is evolving and becoming better by the day, thanks to the new generation of tougher and lighter materials being deployed for the bridge construction and also the advancements in computer modeling. Still, these mammoth structures face the full fury of the forces of nature and their actual response against that predicted from the modeling is a matter of concern and study for the designers and various stakeholders.

Instrumentation & monitoring during every phase of a bridges' life-cycle is a tool for the above study and provides rich information allowing a deeper understanding of its structural behavior. This results in a better planned and less expensive management of the bridge and minimizes the chances of its sudden catastrophic failure. It also contributes to future design improvements.

2 ENCARDIO-RITE GROUP OF COMPANIES

Encardio-rite Group of Companies headquartered in India, have a strength of over 300 personnel including about 100 engineers. It is a more than 50-year-old organization certificated to ISO-9001:2015 quality management standard. The R&D unit of Encardio-rite has been recognized by the Ministry of Science and Technology, Government of India, since 1973. More than 70 % of the total group turnover is earned in foreign exchange from about 50 countries in the world. Encardio-rite has subsidiary organizations in the USA, UK, Greece, Spain, Morocco, UAE, Bahrain, Qatar, and Bhutan.

The main activity of Encardio-rite is to provide online monitoring services for Civil Engineering Structural Projects and Water Resources with remote access to collected data in near real-time. Encardio-rite is one of the few organizations in the world which in addition to providing complete monitoring services also manufactures sensors, dataloggers and has developed advanced software suits in-house, for processing and displaying monitored data and web-based monitoring solutions.

More details about Encardio-rite and its activities are available at http://www.encardio.com.

3 WHY MONITOR A BRIDGE?

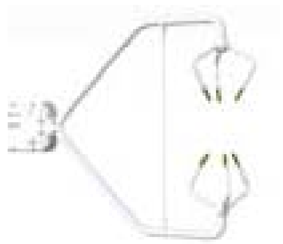
Structural health monitoring of the bridges is carried out for the following purposes:

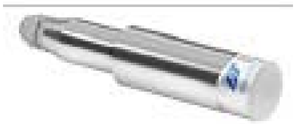
- For detecting, locating, and quantifying deformations of the bridge's structure. This is achieved by the acquisition of data measured in-situ on the bridge.
- For developing a comprehensive understanding of the frequency and amplitude domains on the deviations of the bridge, mainly due to the variation of the thermal gradient, the influence of high winds, and the impact of variations in the traffic load
- For estimating various loads acting on the bridge such as wind, solar radiations, rain, traffic, etc.
- For monitoring construction and repair work being carried on a bridge.
- For monitoring the effect of any third party construction near the bridge.
- For validating design assumptions regarding the static and dynamic behavior of the structure.
- For gaining a deep understanding of the existing structures to improve future designs.
- For predicting the balance service life of the various structural members of the bridge.
- For planning and optimizing the bridge maintenance activities.
- For developing an early warning system for traffic control (for example during seismic events or typhoons).
- For assessing damage to the bridge as a consequence of catastrophic natural events mentioned above.

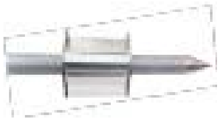
4 BRIDGE MONITORING SOLUTIONS

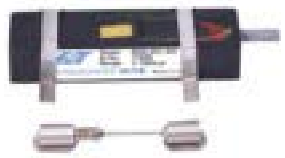
4.1 Sensors

The following are the comprehensive range of sensors offered by Encardio-rite for structural health monitoring of bridges:

Parameter	Instrument	Picture of a typical sensor	Function and application area
Environmental sensors			
Wind speed and direction	Encardio-rite model EWV-102U bi-directional ultrasonic type anemometer Campbell Scientific's CSAT3B Triaxial Ultrasonic Anemometer	 	Wind speed and direction data are required for the restriction of traffic during extreme wind storms. The sensor is installed at the key locations on the bridge's deck/cable pylons.
Visibility & Fog sensor	Campbell Scientific's modelCS-125 present weather & visibility sensor Fronttech's VRE visibility sensor	 	Visibility and fog data are required for cautioning traffic and speed restrictions. This sensor is installed at the key locations on the bridge's deck/cable pylons.
Solar radiation	Encardio-rite's EWR-101S/102T solar radiation sensor	 	The solar radiation data is global data required for the structural analysis of bridge. This sensor is installed at the key locations on the bridge's deck

Barometric pressure	Encardio-rite model EWP-101 barometric pressure sensor		The atmospheric pressure data is global data required for structural analysis of the bridge. This sensor is installed at the key locations on the bridge's deck.
Temperature & Relative Humidity	Encardio-rite model EWH-101T relative humidity & temperature gauge		The ambient air temperature and humidity data are global data required for structural analysis of the bridge. This sensor is installed at the key locations on the bridge's deck.
Rain gage	Encardio-rite model ERG-200/291 rain gage		The data on the intensity and amount of rainfall is global data required for structural analysis of the bridge. This sensor is installed on the bridge's deck within 3 m of the barometric pressure sensor.
Temperature	Encardio-rite model ETT-10TH, ETT-10PT, ETT010V	  	The temperature data of the structure is global data required for structural analysis of the bridge. This sensor is installed at the key locations on the bridge's deck and other structural members. For the road bridges, these are also installed on the asphalt surface nearby of the temperature sensors installed at the soffit of the concrete deck on top of which the asphalt is laid.

Operational and environmental load monitoring sensors			
Dynamic Weigh in Motion sensor (DWIMS)	Kistler's KiTraffic Statistics type 9841A Q-Free's HI-TRAC TMU4	 	DWIMS gives data on the vehicle's velocity, individual axle weight, and relative axle distance. It may also include a camera with vehicle number plate recognition software. It is installed on one of the abutments of the bridge in all lanes to register the vehicular traffic as it enters and leaves the bridge.
Scour Monitoring Sensors	Encardio-rite model EBSM-101S with ultrasonic sensor Encardio-rite model EBSM-101M with sliding magnetic collar	 	Streambed scour is the erosion of sediment at the base of bridge piers, abutments, and other underwater structures. As scour alters the elevation of the riverbed at a pier, the scour monitoring sensors indicate when a bridge becomes structurally deficient and dangerous due to sediment erosion. These sensors are installed at the piers to measure scour. The ultrasonic sensor measuresboth scour development and the refilling. The magnetic type sensor detects scour development only.
Bridge response monitoring sensors			
Static strain gage	Encardio-rite's model EDS-20V-AW VW arc-weldabletype strain gage EDS-20V-EVW embedment type strain gage	  	Measures changes in strain in the structural members of the bridge at slow scan rates. Installed at the decks and piers. Arc-weldable type strain gages can be installed on concrete surfaces also using groutable end blocks. Arc and spot weldable strain gages can also be installed on the surface using epoxy.

	EDS-20V-SW VW spot weldable type strain gage		
Dynamic strain gage	Micro-measurements's model LWK-XX-W250B-350/LWK-XX-W250D-350 weldable strain gage	 	Measures changes in strain in the structural members of the bridge at high scan rates (dynamic monitoring) Installed on the surface of the key structural members of the bridge using spot welding
Load cell	Encardio-rite model ELC-30S-H high-capacity center hole load cell		The load cells are used for monitoring the forces acting on the bridge's cables. These are installed at the cable anchorage points.
Displacement transducer	Gefran's model WPP-A-A-0800-E magnetostrictive displacement transducer Encardio-rite model EDE-VXX vibrating wire linear displacement transducer	 	Thedisplacement transducers are installed at the movement joints of the bridge. Displacement transducers are also used as bearings gauges for monitoring the wear of the bearing. These combined with the tiltmeters installed on the piers give the accumulated movement of the bearing and by that the wear of the bearings.

Tiltmeter	Encardio-rite's model EAN-32 EL electrolytic tilt meter Encardio-rite model EAN-93M MEMS tilt meter	 	Tilt meters measure the change in tilt or deflection of the structural members of the bridge in two directions. Data from the tilt meters are combined with that of the GPS, displacement transducer, and accelerometer to produce correlated global displacements of the entire bridge. These are installed at the top of the piers and other key structural members.
Triaxial accelero-meter	DEWESoft's model IOLITEd 3xMEMS-ACC data acquisition device with embedded triaxial MEMS accelerometer		The output of the accelerometers is a measure of the vibration waveform of the structural member on which they are mounted. The measurements from the accelerometer establish the background for predicting the life span and the movement of the bridge. These are rigidly fixed to the key structural members of the bridge.
Corrosion sensors	Force Technologies Camur II corrosion monitoring system	 	The data from the corrosion sensors are used for the determination of the progress of the corrosion and the ingress of corrosive substances like chlorides and carbon dioxide. These are installed at the bridge's piers and concrete deck at key locations.

4.2 Dataloggers and readout units

Encardio-rite provides a variety of automatic dataloggers and manual readout units for bridge structural health monitoring as mentioned in the table below. These are having a high resolution and high accuracy measurement capability that is much higher than the accuracy class of the individual sensors which measured by them.

Datalogger/node/gateway/readout unit model no.	Description
Geocomp's model I-site HS datalogger	Stand alone, eight-channel high-speed data logger which collects and stores readings at programmed intervals of up to 1000 readings per second per channel. Each channel on the logger measures the output (voltage, current, resistance, or bridge) simultaneously using a high-speed, high-resolution

Datalogger/node/gateway/readout unit model no.	Description
	precision ADC. The datalogger pulls global time from the GPS network, however, an option to sync each data logger to a networked grandmaster clock using the IEEE 1558 standard can be provided. This allows sensors across multiple data loggers to be read at the same time with a precision of better than one microsecond. The data logger can also be programmed to run multiple data logging sessions simultaneously.
Encardio-rite's model ESDL-30 datalogger	The data logger is suitable for automated data collection from SDI-12 digital output sensors and transmission over GSM/GPRS network. The datalogger has 3 channels and each one can have up to 61 no. SDI-12 sensors connected in a daisy chain fashion. Several power supply options are available for the datalogger such as Li batteries, Alkaline batteries, and 12V DC through an external SMF battery or solar power supply.
Encardio-rite's model EDAS-10 datalogger	Suitable for sensors having a variety of output signals-voltage, vibrating-wire, bridge resistance, 4-20 mA, SDI-12, Modbus, etc. Suitable for dynamic monitoring-supports scan rates up to 1000 Hz. Various data transmission options are available such as GSM/GPRS, RF, Ethernet. Runs on a 12V DC battery-backed power supply. Scalable through a choice of measurement and control units and multiplexers.
Encardio-rite's model EWN-01V, EWN-08V, EWN-04A, EWN-01D RF nodes	The RF nodes are available in different variants to suit different sensors-VW single and 8 channel, analog 4 channel-for sensors with millivolt, 4-20 mA, Wheatstone bridge outputs, and digital for SDI-12 output sensors.
Encardio-rite's model EWG-01G RF gateway	The RF gateway collects sensor data from RF nodes, uploads collected data to the Encardio-rite cloud server or a third-party server through the GSM/GPRS network.
Encardio-rite's model EDI-54V portable readout unit	Portable readout unit for VW technology sensors. It uses a smartphone with Android OS as a readout with an app for configuration, retrieving, and viewing sensor data. It can store calibration coefficients of more than 10,000 VW sensors and can store about 525,000 readings from the programmed sensors.
Encardio-rite's model EDI-53L portable readout unit	Portable readout unit for resistance strain gage-based instruments. It can store calibration coefficients of up to 250 numbers of transducers. It can store either around 3600 readings from anyone transducer or about 14 sets of readings from all the 250 transducers

Notes regarding implementation:

1. Encardio-rite provides a range of shielded armored/non-armored cables from 2 to 40 cores for connecting the above sensors to the readout devices/dataloggers. It also provides copper and fiber optic networking cables. Necessary cable conduits, splicing kits, junction boxes, switch boxes, protective enclosures & canopies, lockable manhole covers, masts for environmental sensors, etc. are readily available in standard or customized variants to execute simple to complex instrumentation schemes.

2. Field instruments are vulnerable to lightning damage in areas with a high rate of lightning strikes. The risk increases as the cable length increases. Although a tripolar plasma surge arrestor is inbuilt into most Encardio-rite sensors to protect these against voltage spikes across the input leads, an additional lightning protection system is recommended. Encardio-rite is capable of designing and implementing a lightning protection system for structural health monitoring systems.

3. Encardio-rite can supply, install, and commission necessary servers and software in the bridge control room for configuration, control, acquisition, and storage of data from the various sensors and systems of the SHMS. It can also provide workstations, large display panels, UPSs, furniture, access control system, firefighting, and CCTV systems, etc. for the control room.

4.3 Sensor network

4.3.1 SDI-12 sensor network

Encardio-rite offers advanced automatic dataloggers with an in-built GSM/GPRS modem for data collection of geotechnical instruments with an SDI-12 digital output and transmission to a remote server. The dataloggers can be programmed to measure once every 5 seconds to once every 168 hours.

The measured data is stored, together with the current date, time, and battery voltage, as a data record in the internal non-volatile memory of the datalogger. An alarm is triggered or SMS is automatically sent if any of the pre-determined trigger values are exceeded.

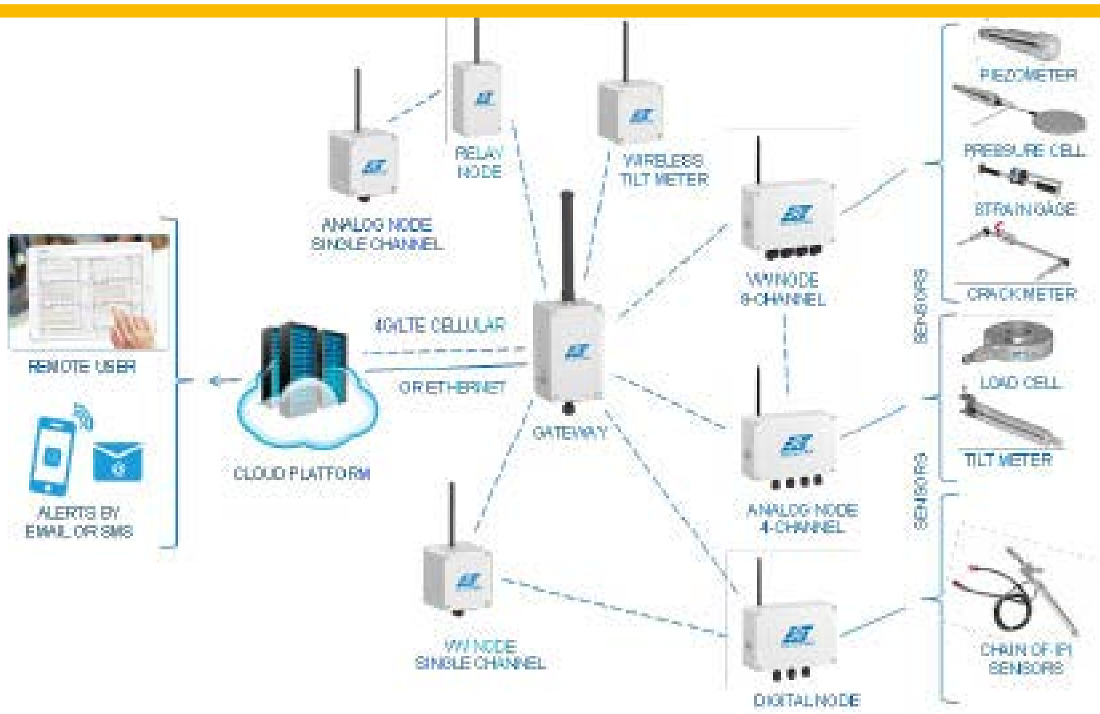
The advantage of the system is that only a single 3 conductor cable is required to interconnect all the sensors in a daisy chain configuration and eventually to the datalogger. SDI-12 is a multi-drop interface that can communicate with multi-parameter sensors.

Suitable interface units are available for non-SDI-12 sensors.

Network of SDI-12 digital interface sensors

4.3.2 RF sensor network

Encardio-rite offers a state-of-the-art multi-hop, wireless mesh network solution that allows real-time monitoring of geotechnical sensors in challenging conditions, with reliable data transfer over long distances without any delay.



Sensor network with wireless (RF) nodes and gateways

The system comprises sensors interfaced nodes that send recorded data to the gateway with over 99% reliability. The gateway uploads the collected sensor data to the central/cloud server.

The unique feature of the mesh network is that even if a node cannot reach the gateway directly, it can send its data to the gateway via other nodes in the network. The mesh network allows all nodes to talk to each other, thus allowing them to relay data from other nodes to the Gateway. This ensures that data from all nodes are transferred to the gateway (and hence cloud server) without any delay.

The wireless system eliminates the need for running lengthy cables, thus offering benefits such as convenient installations, cost & time savings, remote monitoring of hard-to-access locations, and easy maintenance.

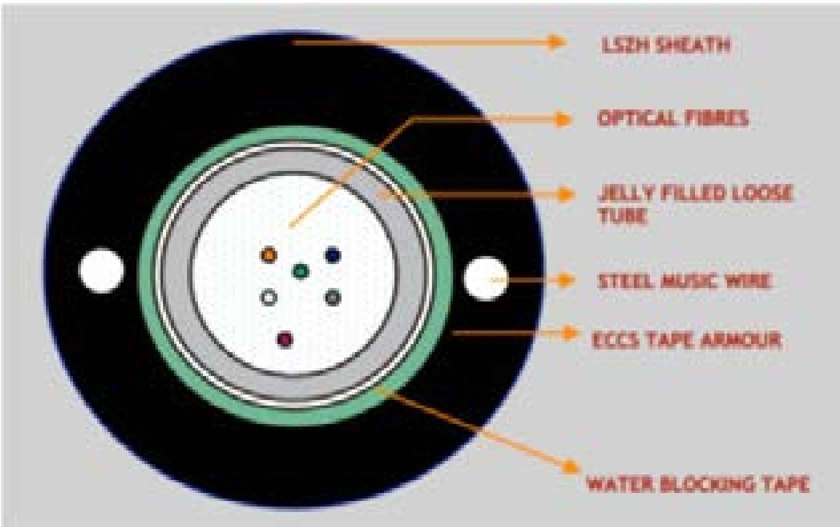
4.3.3 Ethernet sensor network

Fiber optic cable-based backbone networks offer a fast and reliable data transfer from the sensors subnets spread over a long span bridge to the central monitoring server. These feature dual ring topology and in the event of a switch failure, data automatically flows across to the other ring. It is implemented using layer 2 and layer 3 industrial-grade network switches and armored single-mode fiber optic cable. It terminates in the server located in the bridge's control room.

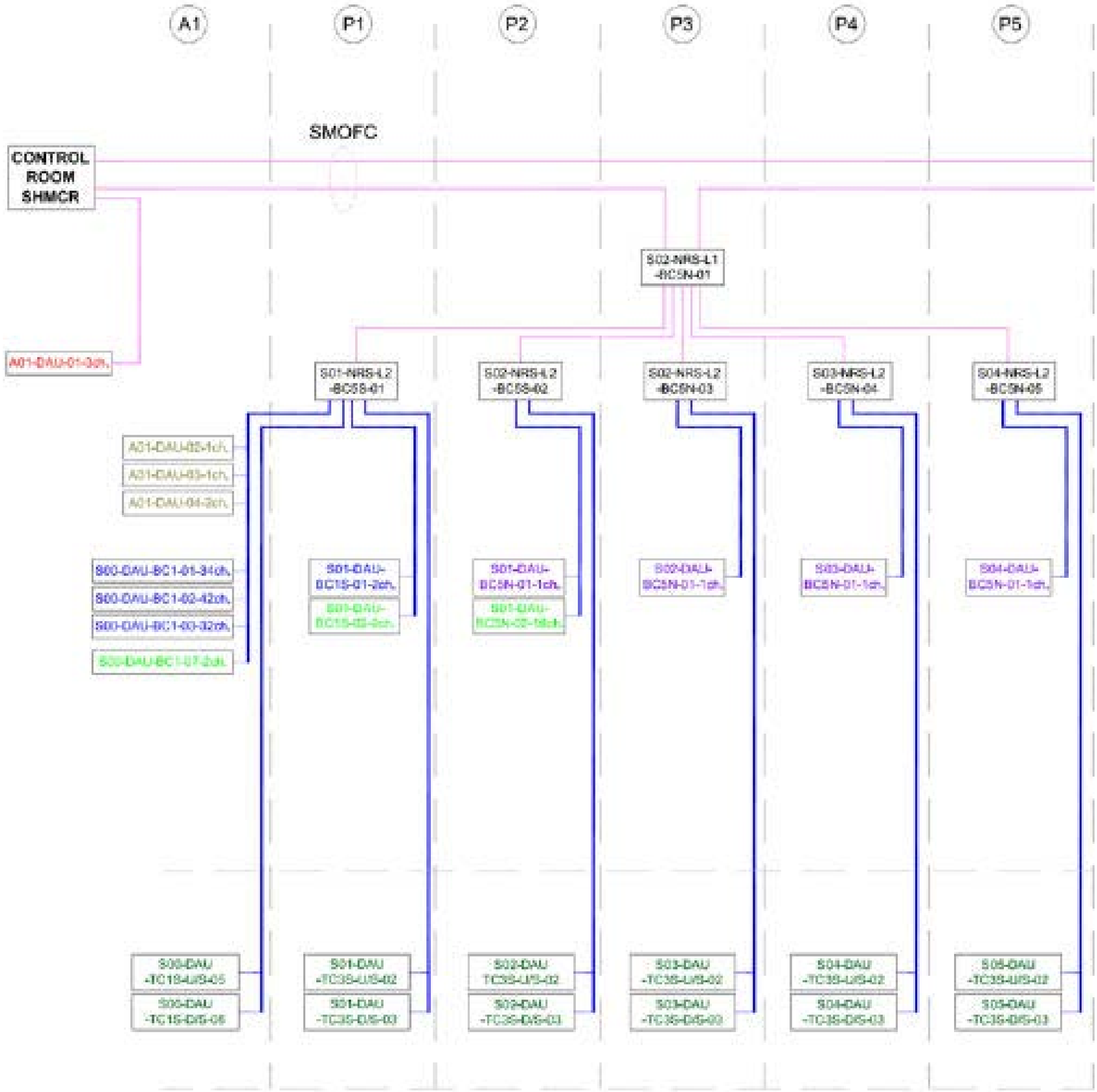
The switches have modular, fanless construction and are housed in sheet metal NEMA4 rated enclosures placed on the bridge. They are suitable for deployment in harsh environmental conditions. The switches have redundant power supply inputs and inbuilt surge/noise immunity. These switches also have a very high mean time between failure figures (MTBF > 300,000 hours or > 34 years).

The layer 3 switches will operate in a redundant mode such that if the master switch fails another switch will be automatically promoted as the master maintaining the ring operation.

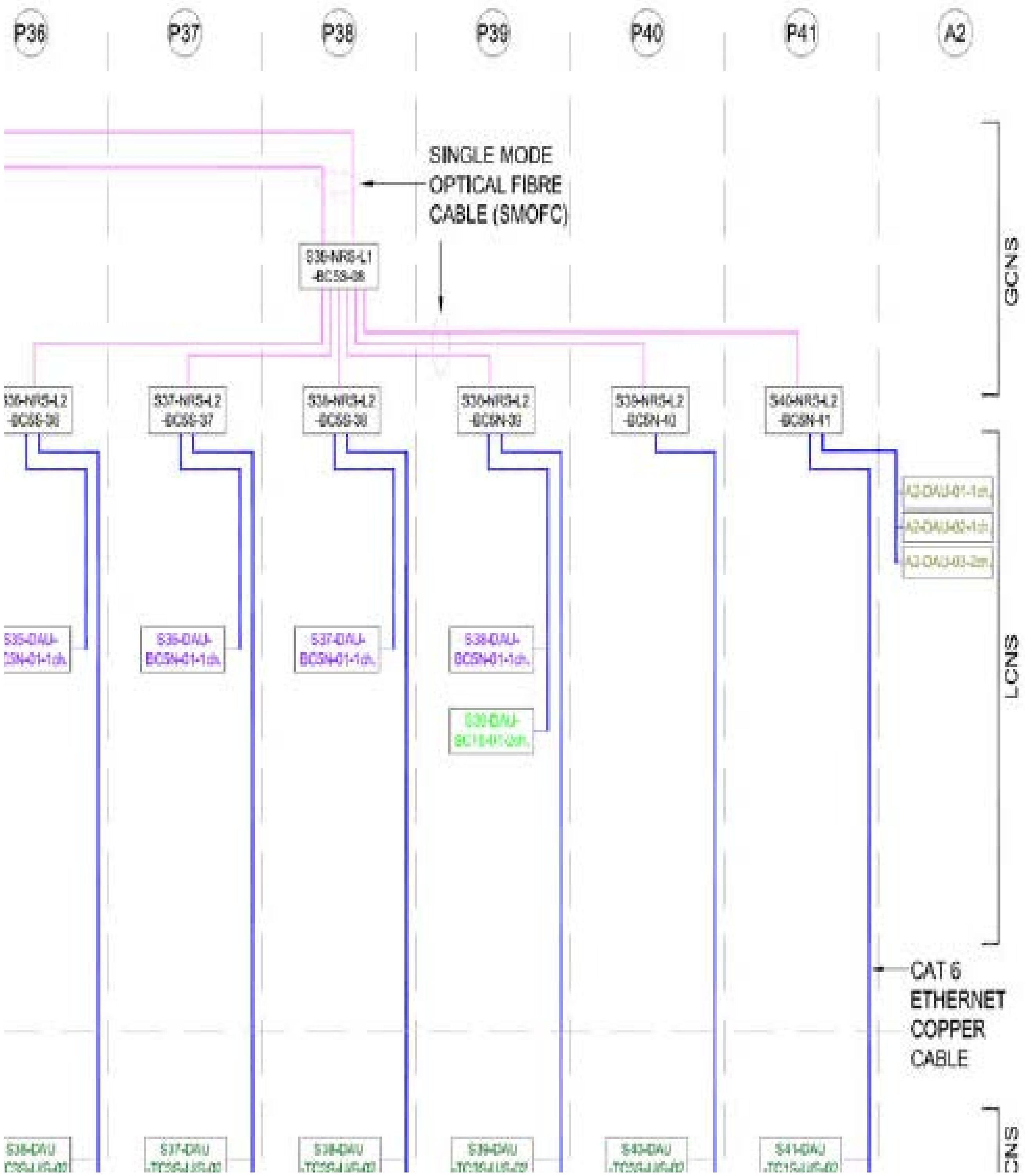
Various types of data loggers and sensors connect to the backbone network, also referred to as Global Cabling Network System (GCNS), through the layer 2 network switches through FO cables. The dataloggers in-turn connect to the layer 2 switches through CAT6 copper cables where the distance is less than 60 m and with FO cables where the distance is more. The sensors connect to the datalogger through shielded copper cables which reduces the impact of electrical noise on the signals and also lowers electromagnetic radiation.



Network Switch (above) and FO cable cross section (below)



A1
P1
P2
P3
P4
P5
SMOFC
CONTROL ROOM SHMCR
S02-NRS-L1 -BC5N-01
S01-NRS-L2 -BC5S-01
S02-NRS-L2 -BC5S-02
S02-NRS-L2 -BC5N-03
S03-NRS-L2 -BC5N-04
S04-NRS-L2 -BC5N-05
A01-DAU-02-1ch.
A01-DAU-03-1ch.
A01-DAU-04-2ch.
S01-DAU-BC1S-01-2ch.
S01-DAU-BC5N-01-1ch.
S00-DAU -TC1S-U/S-05
S00-DAU -TC1S-D/S-06
S01-DAU -TC3S-U/S-02
S01-DAU -TC3S-D/S-03
S02-DAU TC3S-U/S-02
S02-DAU -TC3S-D/S-03
S03-DAU -TC3S-U/S-02
S03-DAU -TC3S-D/S-03
S04-DAU -TC3S-U/S-02
S04-DAU -TC3S-D/S-03
S05-DAU -TC3S-U/S-02
S05-DAU -TC3S-D/S-03



4.3.4 EtherCAT sensor network

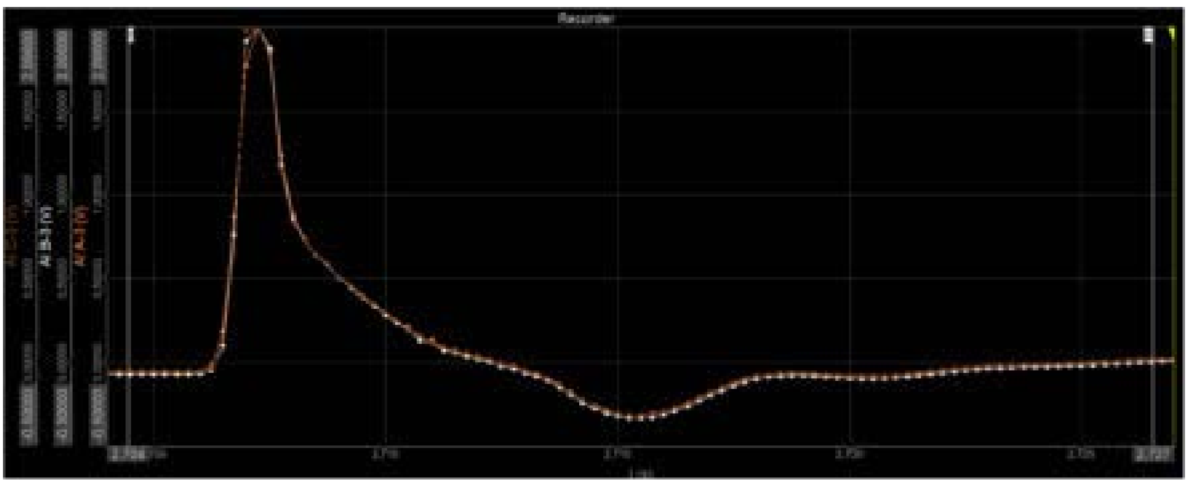
A network of triaxial MEMS accelerometers integrated with data acquisition devices could be established on a bridge using EtherCAT protocol over CAT6 cabling, resulting in improved performance a significant cost saving. Separate high-speed data loggers need not be procured and installed for such a network. Analog to digital conversion is done inside the integrated device, eliminating noise pick up in the analog cabling.

EtherCAT is an ultra-high-speed real-time Ethernet that is preferred for real-time control applications. The unique way EtherCAT process frames make it the fastest industrial Ethernet technology.

EtherCAT based accelerometer network

The accelerometers are often read to a maximum of 1000 samples per second. The data from different accelerometers installed on the bridge will need time synchronization better than 10 microseconds to reduce phase errors while correlating the signals amongst themselves. The use of EtherCAT leads to a timing jitter significantly less than 1 microsecond. This kind of timing accuracy cannot be achieved with the standard TCP/IP over Ethernet connections.

All accelerometers deployed on the bridge could be connected in a daisy chain manner using CAT6 cable to form an EtherCAT bus. the EtherCAT bus is connected to a customized compact PC at the end of the bus.



Acceleration data from 3 diff. Accelerometers that were fixed together and excited by a drop test. The data is fully synchronized

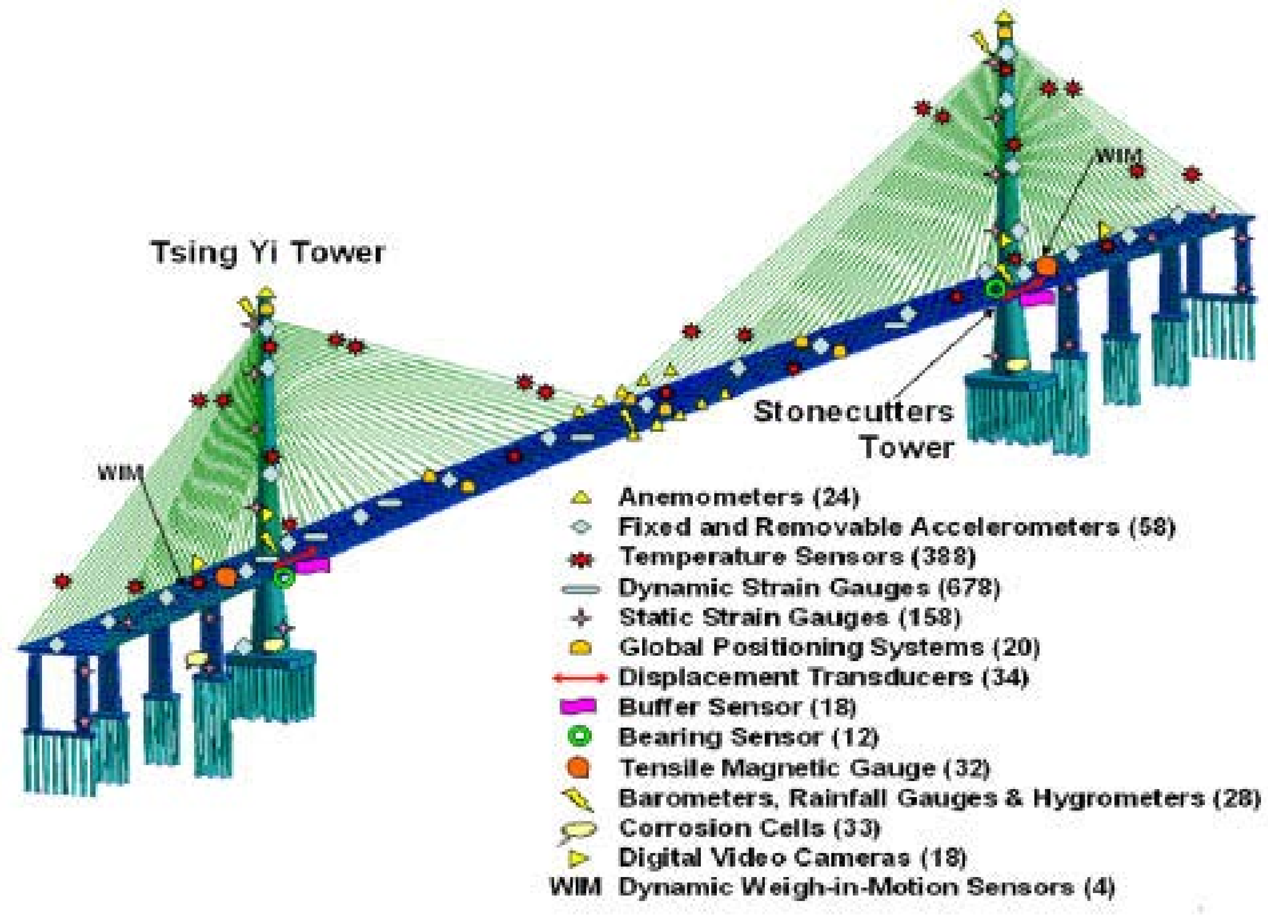
The PC running the proprietary software receives acceleration samples over the EtherCAT protocol. The scaling is automatic in the software making the data in terms of g or m/s2 readily available. The PC also transfers the accelerometer's data to the FO backbone.

4.3.5 Time synchronization of networked devices

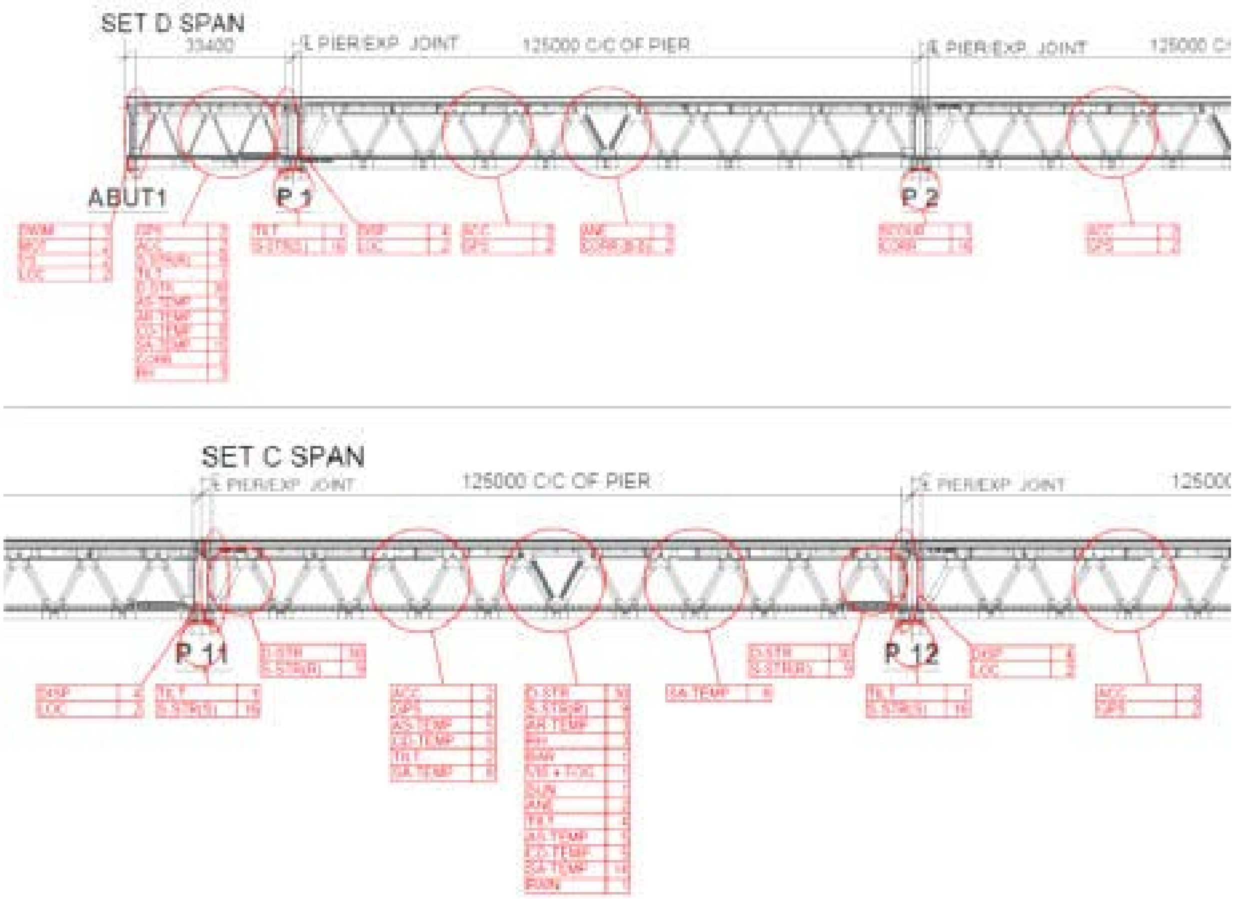
An NTP (Network Timing Protocol) server is used for time synchronization of all networked devices. This server is located at the bridge's control room and is connected to a GNSS antenna which allows the time signal to be accurate to better than 0.5 microseconds of the real-time of day.

While designing the network it should be ensured that all network devices and Data Acquisition Units supplied should have the feature that they can synchronize their time with the NTP server present in the network. So, all logged data points will have timestamps that are accurate to better than 0.5 microseconds to the reference time signal.

4.4 Typical instrumentation schemes



Typical instrumentation scheme of a cable-stayed bridge



S-STR (R)	STATIC STRAIN GAUGE, ROSETTE TYPE
S-STR (S)	STATIC STRAIN GAUGE, SINGLE TYPE
D-STR	DYNAMIC STRAIN GAUGE
SA TEMP	STEEL DECK TEMPERATURE
AR TEMP	AMBIENT AIR TEMPERATURE
RH	RELATIVE HUMIDITY
AS TEMP	ASPHALT TEMPERATURE
CD TEMP	CONCRETE DECK TEMPERATURE
BAR	BAROMETER
ANE	ANEMOMETER
VIS + FOG	VISIBILITY
RAIN	RAINFALL
BAR	BAROMETER
SUN	SUN RADIATION
TILT	2D TILTMETER
ACC	ACCELEROMETER
GPS	GPS
DISP	DISPLACEMENT SENSORS INSTALLED AT EXPANSION JOINTS
TOT. STAT	TOTAL STATION PRISM
VS	VIDEO SURVEILLANCE
BCT	SEISMIC MONITOR SENSOR
SCOUR	EITHER GRAVITY OR ACOUSTIC SCOUR DETECTION
DWIM	DYNAMIC WEIGH IN MOTION SENSOR
CORR	CORROSION SENSOR
LC	LOAD CELL

Typical instrumentation scheme of a double deck steel & concrete composite Warren type truss bridge

4.5 GNSS

GNSS has become presently an established technology for bridge monitoring operations. A properly configured GNSS measurement system can meet most static and dynamic measurement needs for absolute positioning and relative displacement and that too in the frequency domain.

Twenty years ago, from now the hardware i.e., the GPS/GNSS antennas were very expensive and the use of this technology for bridge monitoring was limited only for the bridges with a large budgetary allocation for monitoring purposes. Over the last 5 years, the price of the GNSS hardware has significantly reduced. Telecommunications solutions such as 4G and 5G are also becoming prevalent allowing fast wireless connectivity. GNSS data processing algorithms have also followed the same trend and made tremendous advancements.

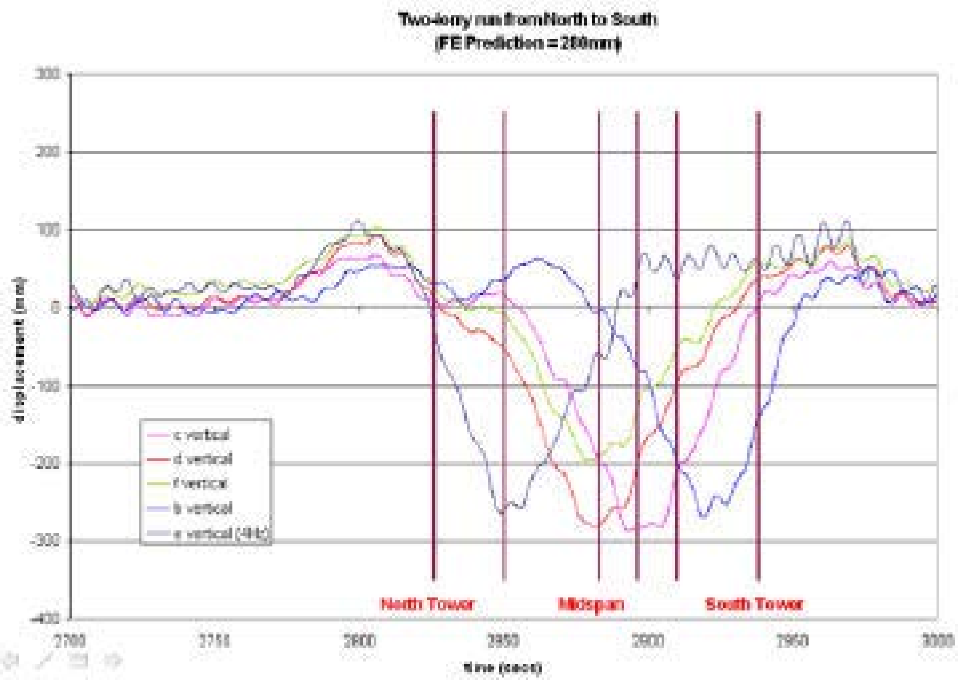
With 4 GNSS constellations viz. GPS, GLONASS, BEIDOU, and GALILEO, 25 satellites can be tracked by a GNSS receiver on an average. Owing to the above and enormous advancements made in the receiver hardware and software, and signal processing & filtering techniques, millimeters accuracy level can be achieved in real-time. Processing algorithms have evolved in a way that 3D results can be obtained in real-time at 20 to 50 Hz sampling rates.

Advantages of monitoring bridges using GNSS technology are as follows:

Reference GNSS station of a bridge monitored using GNSS rover stations

- Works 24/7/365 without maintenance or calibration
- Insensitive to local atmospheric conditions
- Entirely digital, no mechanical components
- No inter-visibility required between the measurement points
- Providing positions and time reference (synchronizing other sensors)
- Full traceability

For bridge monitoring applications GNSS rover stations are installed at the key structural members of the bridge with two reference stations placed symmetrically and orthogonally to the bridge's axis, at around 1/3 of the span distance away from the nearest pier. One of the two reference stations works as a master reference station broadcasting the RTK correction data for fixing the position of each of the rovers stations and the other acts as a monitoring station for



Bridge displacement data from GNSS sensors

the integrity monitoring of the master reference station as well as serving as a hot-standby backup reference station in case of malfunction.

For networking purposes, the reference stations and the rover stations can be connected to level 2 switches using CAT6 cables. These switches can be uplinked to the network's backbone through layer 3 switches using FO cables. Thus, all the rover stations shall be sending the data to the central server in the bridge's control room in a streaming mode.

A proprietary post-processing software running on the server processes the data and outputs the results. The software deploys Kalman filtering to mitigate noise in the results and also predicts the next epochs solution to issue alarms and warnings if they are configured.

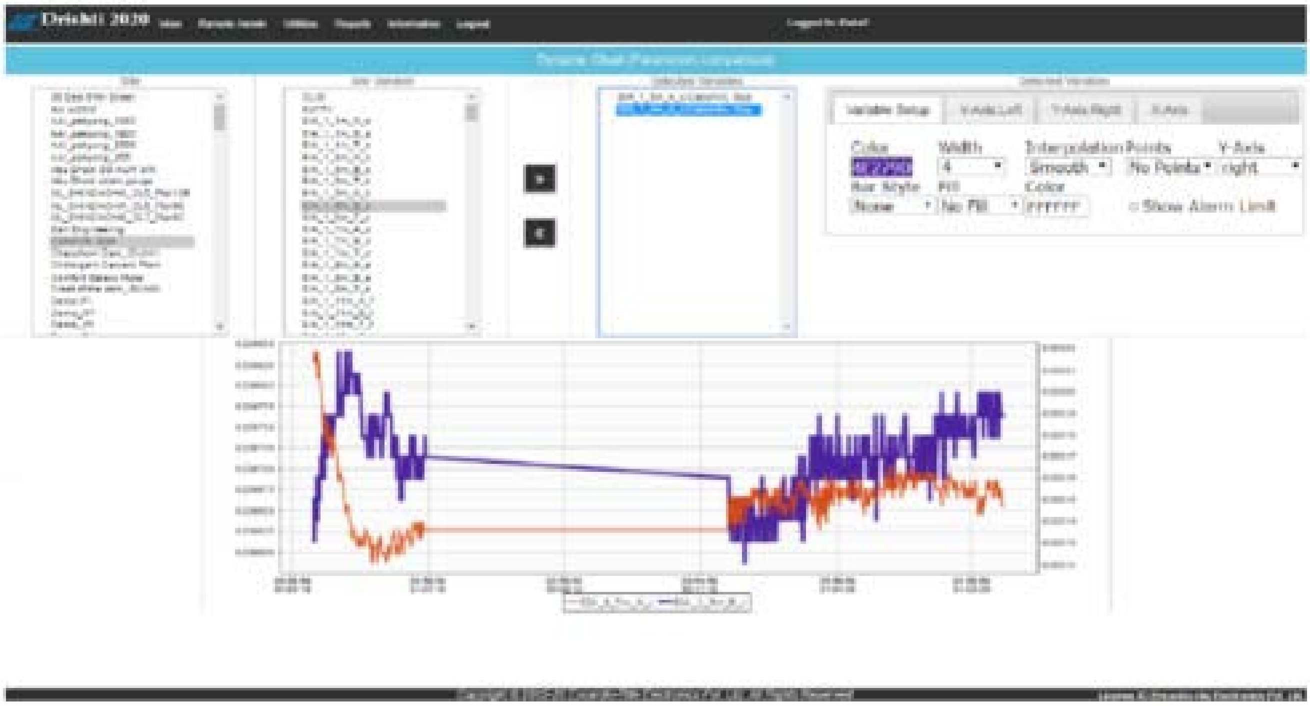
4.6 Data management software

Encardio-rite offers powerful yet user-friendly data management software suits for the safety monitoring of bridges. The software acts as a data collection agent, a database server, and a web server. These can either be hosted on a high-reliability server computer or a secure cloud-based server. The host computer periodically collects data from the remote data loggers which can be geographically spread over a large area, through cellular phone/FO cable networks. These are capable of handling large quantities of data from a variety of sensors to assess bridge performance in real-time.

Multiple authorized users at different locations assigned with an individual password may view any data or report from the structure simultaneously. Graphs & reports can be viewed using popular web browsers like Microsoft Edge, Google Chrome, or Mozilla Firefox. The users may interact with the software on any internet-enabled device. The software offers Google Earth navigation, dynamic charts, graphical navigation, scatter plots, heat maps for a thorough interaction.

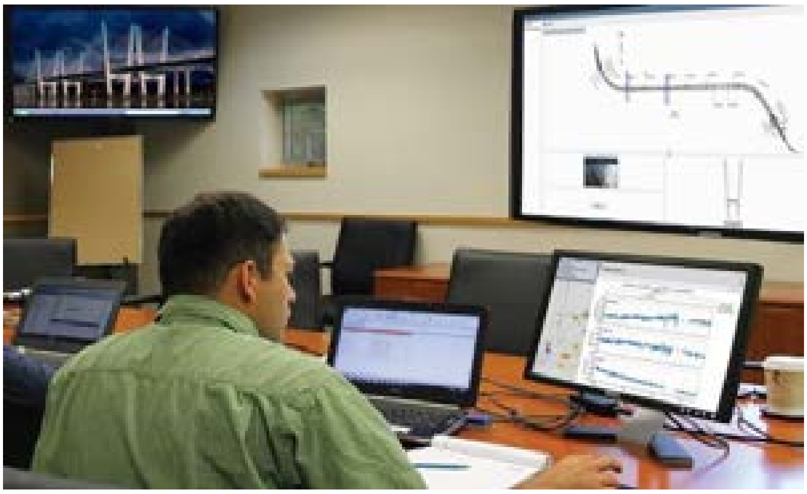
Details like sensor identification tag, last recorded sensor reading, and values of programmed alert levels can be viewed on the first page of the site that shows the location of installation. If any one of the alarm levels exceeds, the sensor location turns to a red dot. Clicking the pop-up table brings up an associated data window where the sensor data can be seen either as a table or as a graph. Short and long-term bridge behaviors can be easily observed from the historical data view and summary reports.

View from the data management software showing location of sensors installed on a bridge



Dynamic chart view for correlation of data from multiple sensors

Data access on smartphone



Typical bridge control room

Site administrators can set warning and serviceability limits on the data which are generally considered as “alert level” and “evacuate level”. The software can also be programmed to automatically send SMS or e-mail alert messages to selected users as soon as any sensor data crosses its predefined alarm levels, either while going above or going below the alarm level.

Encardio-rite designs, installs, automates, operates, upgrades, maintains, and advises on automated performance monitoring systems for almost any structural health monitoring application. It also offers public cloud-based web data monitoring services (WDMS).

5 NON-CONTACT METHODS OF MONITORING

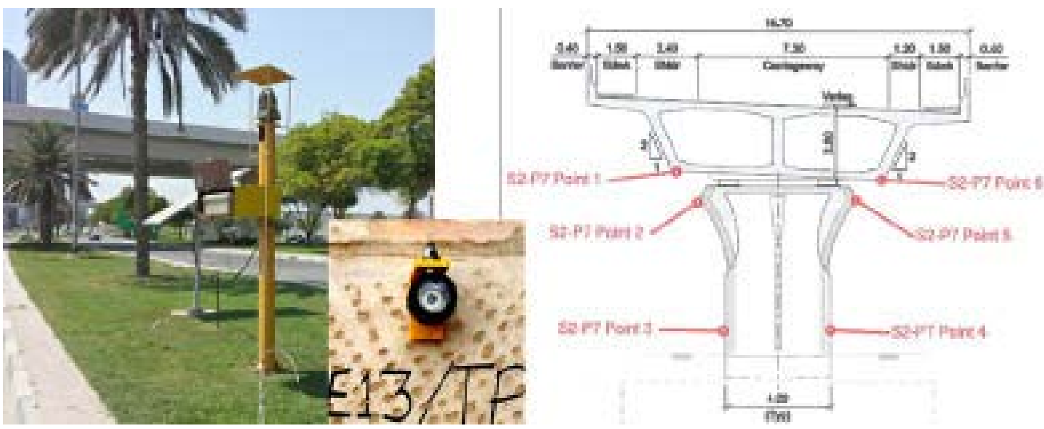
5.1 Automated total station

The near real-time 3D-deformation monitoring system is a systematic tracking of any alteration that may take place in the shape or dimension of a bridge as a result of stress, load, aging, etc.

The above deformation monitoring system consists of high accuracy automated total stations (ATS) that have the ability of auto-target recognition (without any human interference). Each ATS has a dedicated control box that includes a rugged field computer running special software. This control box manages the total station and schedules the frequency of the measurements, the addition or subtraction of monitor benchmarks, the filters of acceptance or repetition of each measurement, the atmospheric corrections in distance measurements, the calculation, and repositioning of the total station, etc.

The on-site system transmits the collected raw data to a remote server/computer via GPRS/GPS. The whole system can be controlled/re-configured remotely after installation at the site. Raw data is processed into meaningful results by specialized software. The system has the facility of alert notifications through SMS and (or) e-mail to the authorized team for any result exceeding present alarm and critical levels.

The system provides accurate, continuous, real-time data, eliminating any human error/delay in manual data. The raw data is processed, analyzed and the result is majorly used for predictive maintenance, alarming for safety.



Web-based monitoring of lateral movement and settlement using robotic total stations and prism targets

5.2 Laser scanning

Laser scanning is an advanced method of surveying and conducting geometric profiling of bridges that are generally difficult to reach or gain access to. Recent developments in laser scanners and software have made it one of the fastest, convenient and cost-effective tools to accurately monitor bridges in three-dimensions. Drone mounted laser scanners are best suited to scan large/high bridges.

The advantage of laser scanning is that the measurements are not limited only to specific prism spots, but covers all the exposed surfaces. Completion of the fieldwork results in a geo-referenced point cloud which, due to its great density and its ability to bear information on the reflectivity and/or the color of each point, comes close to the term, 'virtual reality'.

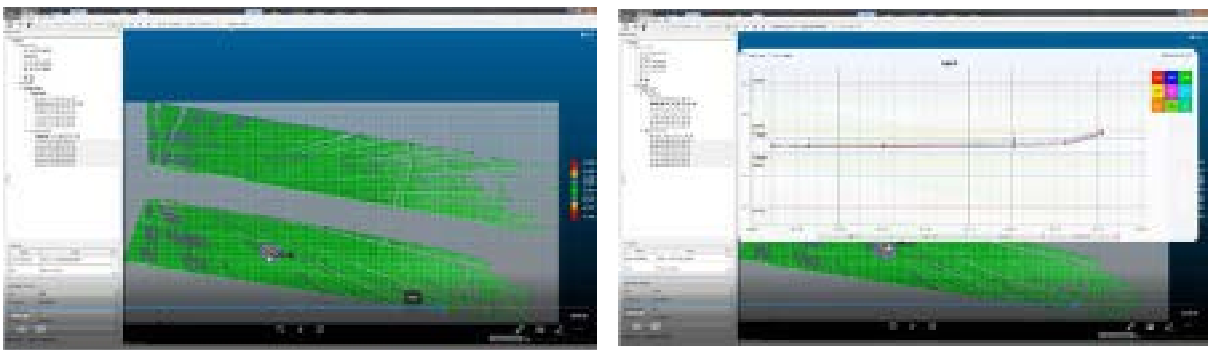
OPSIS is a software developed by Encardio-rite to overcome the impediment caused by the vast amounts of data LiDAR generates. The idea within its core is to perform operations over the raw data from the LiDAR to obtain a significantly smaller data set to carry out the analysis.

The task of monitoring the deformations or displacements of the scanned objects to perceive possible changes using OPSIS comes down to processing the subsequent point clouds obtained in different epochs using the same projection surface and grid obtained as the best fit for the initial point cloud. If significant changes in the object's geometrical form occur, variations of the cell's mean values and color will make them easily detectable.

What makes this approach unique and better than other commonly used existing software is the feature that it not only gives a point cloud pair comparison but also provides a linear diagram visualization of the deformation history of each grid cell. Due to the lighter nature of the new software, it takes significantly lesser time to process the results and make the same available online, almost in real-time.

To summarize, the results of laser scanning gives us:

- Surveying of current state and of «as constructed» state
- Virtual reality creations; Virtual tour videos
- Geometric documentation of the structure
- Creation of 2D & 3D products (sections, facets, 3D models, etc.)
- Identification of deformations



Deformation monitoring using OPSIS software

5.3 Drone survey

Inspection of large bridges is difficult to reach or gain access to at times. The use of Unmanned Aerial Vehicles (UAV)/ Drones is best suited for such applications.

UAVs/Drones are unmanned and remotely-piloted aircraft that follow a pre-programmed path for takeoff, flight, and landing. These aircraft are equipped with HD/IR/Thermal cameras that capture images and videos. Using UAVs/drones to video, model, and scan for cracks, erosion, corrosion, and defects in the bridges, that would otherwise require the inspector to use a rope/harness or erect access scaffolding, is a safer, faster, and smarter choice. It greatly reduces the costs associated with the inspection This technology is useful during the construction process also-as the development occurs, managers have difficulty maintaining a true picture of the site. With UAV-based mapping at regular intervals, this information gap can be closed.

Bridge inspection using drone

6 CONCLUSIONS

The automated bridge monitoring system, if thoughtfully designed, detailed, and implemented, provides tremendous amounts of information that will allow an accurate assessment of the condition to which the bridge is subjected as well as the condition and performance of the structure with minimal effort.

As the bridge design and materials get advanced, bridge monitoring is evolving towards 'Structural Health Monitoring' which uses advanced operational modal analysis to detect failures early and initiate inspections based on the reports and statistics. Modern bridge structural health monitoring systems analyze data from a variety of sensors installed on a bridge and calculate the remaining lifespan of the structural components of the bridge. Presently, BIM is also being used with the SHMS systems to make the process more efficient and effective

Owing to the critical nature of the bridges, the instrumentation and software used and the manpower deployed for installation, monitoring, and maintenance of instruments have therefore to be top quality and reliable. Encardio-rite group of companies with experience in manufacturing and monitoring of almost half a century are some of the best manufacturers and service providers in the field